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The main objective of this grant is to quantify the concept of ideal microstructures for fracture resistance. To approach this goal, a variety of steels and heat treatments was investigated. Of particular interest was the resistance of different steels to failure by shear instability, which is much less well understood than tensile instability. While some information on shear-crack initiation is available in the literature, evidence on shear-crack propagation is (cont'd on back)			
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Key to Fig. 2

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IDEAL FRACTURE-RESISTANT MICROSTRUCTURES

Final Report

by

A. R. Rosenfield, J. P. Hirth, M. Manoharan, and S. Raghavachary

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STATEMENT OF THE PROBLEM

The main objective of this grant is to quantify the concept of ideal microstructures for fracture resistance. To approach this goal, a variety of steels and heat treatments was investigated. Of particular interest is the resistance of different steels to failure by shear instability, which is much less well understood than tensile instability. While some information on shear-crack initiation is available in the literature, evidence on shear-crack propagation is very limited and mainly confined to very tough steels.

SUMMARY OF THE MOST IMPORTANT RESULTS

Experiment

Research on our earlier Grant (P-18399-MS) used a 1 % Cu, 0.05 % C steel (ASTM A710A) which has extremely high fracture toughness, but whose strength is limited to approximately 550 MPa. Fracture toughness in combined tension/shear was measured by use of compact specimens containing precracks whose planes were oriented at varying angles to the specimen face. Three additional steels, whose compositions are given in Table 1, were chosen for detailed study and comparison with A710A:

Steel D is a high-C alloy steel which was heat treated to produce a bainitic microstructure, optimizing strength and toughness.

Steel E is a Cu-Ni-Mn steel and also is higher in C than A710A. It was overaged to optimize toughness.

Steel G is a very clean, tough steel, which is resistant to temper embrittlement. It underwent a complex heat treatment, with the final tempering temperature being 590 C.

Figure 1 is characteristic of all steels, in that the Mode I (tensile) toughness decreased linearly with an increasing Mode III (transverse shear) component. Quantitatively, the behavior of Steel D was quite

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different from that of the others, since the slope of its line in Figure 1 is quite small. In contrast, the other steels exhibit slopes equal to, or slightly shallower than, that of Steel G. The fracture surfaces of Steel D are also different, exhibiting mainly quasi-cleavage while the others exhibit dimpled rupture. From these results, it can be suggested that insensitivity to shear loads is incompatible with the high-energy fracture mechanism.

Theory

Several small theoretical tasks were undertaken in support of the Grant. One involved investigating whether brittle fracture in steel could be eliminated by limiting the size of the largest microstructural particle. The upper limiting particle size was calculated to be in the range from 0.1 to 1.0 μm . Unfortunately, particles of this size are very difficult to eliminate in practice, particularly inclusions such as sulfides.

To provide a second method of producing tough materials, an estimate was made of the effects of processes occurring behind the tip of an advancing crack on the apparent fracture resistance of the material undergoing fracture. Cleavage fracture in steel leaves unbroken ligaments in its wake and it was shown that these significantly reduce the driving force at the crack tip. Since the same mechanism controls the fracture of fibrous composites, it should be possible to apply the new analysis to the design of this latter class of material.

A third method to improve toughness would be to insure that the fracture surface is very rough. To put this idea on a quantitative basis, an initial effort to formulate fracture mechanics in terms of fractal geometry was made. A correlation was found between the fractal dimension of the fracture surface and relative toughness of an aluminum alloy and alumina ceramics.

Efforts were also initiated on modeling mixed-mode fracture using mass points interacting via pair potentials. It was found that a simple pair potential model cannot adequately represent elastic/plastic materials.

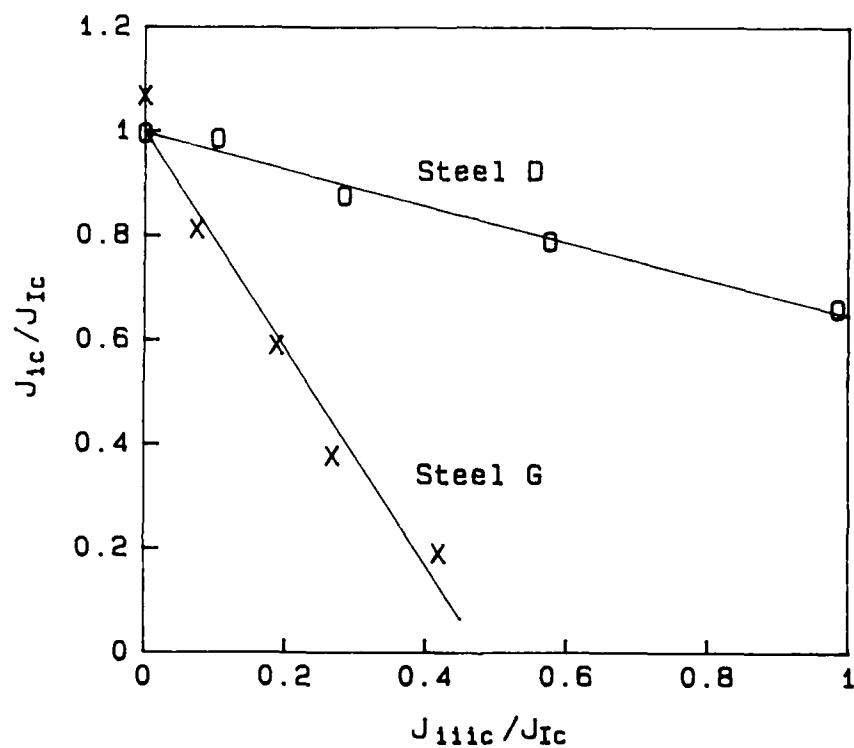


FIGURE 1: EFFECT OF TRANSVERSE SHEAR LOADS ON TENSILE FRACTURE TOUGHNESS

TABLE 1. COMPOSITION OF EXPERIMENTAL STEELS

ELEMENT	STEEL D WT. %	STEEL E WT. %	STEEL G WT. %
C	1.25	0.29	0.25
Mn	0.49	0.97	0.05
P	0.004	0.003	0.003
S	0.003	0.003	0.0015
Si	---	0.007	0.02
Cu	---	0.83	---
Ni	---	0.98	3.70
Cr	1.51	0.001	1.70
Mo	---	0.002	0.40
Al	1.63	0.000	---
V	---	0.001	0.12
Zr	---	0.000	---
B	---	0.0001	---
Sn	---	---	0.003
As	---	---	0.003
Sb	---	---	0.002

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